Project Final Report
Regional Forest-ABL Coupling: Influence on CO_2 and Climate

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1. Summary of Completed Project

Ecosystem CO_2 exchange and atmospheric boundary layer (ABL) mixing are correlated diurnally and seasonally. Tracer transport models predict that these covariance signals produce a meridional gradient of annual mean CO_2 concentration in the marine boundary layer that is half as strong as the signal produced by fossil fuel emissions. This rectifier effect has been predicted by many inversion models. However, observations to constrain the strength of the rectifier effect in nature are lacking. The fundamental objective of this project was to measure the strength of these covariance signals between ecosystem CO_2 flux and ABL dynamics by employing ABL profiling systems at eddy flux tower sites. We found that (1) the observed diurnal and seasonal covariance between ecosystem CO_2 fluxes and ABL turbulent mixing are strong; (2) the inversion model underestimates the diurnal and seasonal covariance; (3) the rectifier effect in the model appears to be too weak. However, these results are subject to significant uncertainties associated with the use of a point measurement to represent an area, fair weather bias among the data and instruments, and nonlinear transport processes between continental and marine boundary layers.

2. Technical Information

2.1 ABL Profiling System and Eddy Flux System

A National Center for Atmospheric Research Integrated Sounding System (ISS) was deployed about 5km east of the WLEF-TV tower in the Chequamegon National Forest. The tower is instrumented for high-precision, high-accuracy CO_2 mixing ratio measurements at six levels up to 396m above ground (Bakwin et al., 1998) and continuous eddy-covariance flux measurements at three levels up to 396m (Berger et al., 2001). The ISS, including boundary layer radar profiler, radio acoustic sounding system, and rawinsonde system was operated at WLEF from March through October of 1998 and 1999. The NCAR ISS was also deployed at the Walker Branch flux tower in Oak Ridge, Tennessee from March through November of 1999. Continuous observations of

atmospheric structure including radar reflectivity and horizontal wind profiles were collected at each site and rawinsondes were launched at midday once per week.

2.2 Derivation of ABL dynamics

Boundary layer depths were derived from the radar reflectivity data at WLEF and Walker Branch. A combination of tall tower and radar boundary layer depths from WLEF were used to describe the seasonal evolution of the diurnal mixing depth and its relationship to local turbulent forcing and synoptic conditions (Yi et al., 2001). Boundary layer depths for March through October of 1998 and 1999 at WLEF and May through November of 1999 at Walker Branch are available on-line (http://cheas.psu.edu). An empirical relationship between the mixed layer depth and the cumulative surface virtual potential temperature flux was obtained allowing estimates of mixed layer depth from measurements of surface virtual potential temperature flux (Yi et al., 2001). Laser ceilometer observations of cloud base height and cloud fraction have been collected around WLEF during both years. The data sets of continuous, hourly cloud base height and cloud fraction from 1998 to 2001 around WLEF are available on-line (http://cheas.psu.edu).

2.3 Comparison between Observation and GCM Simulation

The comparison (Yi et al., 2003) between CSU GCM boundary layer depths and our observations, as well as the covariance between mixing depth and surface fluxes (the forcing for the rectifier effect) showed that the continental rectifier forcing is significantly underestimated on diurnal and seasonal time scales by the simulations of Denning et al. (1995). The seasonal covariance is responsible for the bulk of the predicted rectifier effect. Hence, the rectifier effect in the model appears to be too weak. There are uncertainties in this analysis regarding seasonality of transport between the continental and marine boundary layers, representativeness of the single observing site and a bias towards fair weather observing conditions.

2.4 Future Work

Yi et al. (in preparation) used the empirical formula from Yi et al. (2001) to estimate ML depths from surface sensible heat flux measurements at Harvard Forest tower site (HF) from 1992 to 2001. We found that the ML depth at HF in the growing season is similar to winter, while deep mixing happens in spring as the forest ecosystem releases CO_2 to atmosphere. The seasonal covariance observed from HF is different than WLEF. In order to examine the regional variability of the covariance, we need to extend this analysis to more sites.

Project-related journal publications:

Bakwin, P.S., K.J. Davis, C. Yi, S.C. Wofsy, J.W. Munger, L. Haszpra and Z. Barcza, Regional carbon dioxide fluxes from mixing ratio data, *Tellus*, submitted, 2003.

Davis, K.J., P.S. Bakwin, C. Yi, B.W. Berger, C. Zhao, R.M. Teclaw and J.G. Isebrands, Long-term carbon dioxide fluxes from a very tall tower in a northern forest: Annual cycle of CO2 exchange, *Global Change Biology*, in press, 2003.

Denning, A.S. et al., Simulated and observed variations in atmospheric CO2 over a Wisconsin forest, *Global Change Biology*, in press, 2003.

Yi, C., K.J. Davis, P.S. Bakwin, and B.W. Berger. Long-term observations of the dynamics of the continental planetary boundary layer, *J. Atmos. Sci.*, 58, 1288-1299, 2001.

Yi, C., K. J. Davis, P. S. Bakwin, A.S. Denning, N. Zhang, A. Desai, J. Ch.-H. Lin, C. Gerbig, and S. C. Wofsy, The observed covariance between ecosystem carbon exchange and atmospheric boundary layer dynamics in North Wisconsin, submitted: *Journal of Geophysical Research*. 2003

Yi, C., K. J. Davis, P. S. Bakwin, The regional variability of covariance between ecosystem carbon exchange and atmospheric boundary layer dynamics, in preparation.

Conference proceedings:

Davis, K.J., C. Yi, B.W. Berger, R.J. Kubesh and P.S. Bakwin, 2000. Scalar budgets in the continental boundary layer, Proceedings of the 14th Symposium on Boundary Layer and Turbulence, 7-11 August, American Meteorological Society, Aspen, Colorado, 100-103.

Yi, C., K.J. Davis, B.W. Berger, and P.S. Bakwin, 2000. On development of convective boundary layers, Proceedings of the 14th Symposium on Boundary Layer and Turbulence, Aspen, Colorado, 7-11 August, Amer. Met. Soc., 223-226.

Davis, K.J., B.C. Cook, W.B. Sea, C. Yi, P.V. Bolstad, J. Martin, P.S. Bakwin, C. Zhao, J.G. Isebrands, R. Teclaw and V. Gutschick, 1998. The Chequamegon Ecosystem-Atmosphere Study: Overview and preliminary results. Proceedings of the 23rd Conference on Agricultural and Forest Meteorology, Albuquerque, NM. American Meteorological Society, 51-53.

Davis, K.J., C. Yi, P.S. Bakwin, W.M. Angevine, C. Zhao, J.G. Isebrands and R. Teclaw, 1998. Profiles, fluxes and entrainment of carbon dioxide observed from a very tall tower. Proceedings of the 4th International Symposium on Tropospheric Profiling: Needs and Technologies, September, Snowmass, Colorado, 73-75.

Presentations:

Davis, K.J., P.S. Bakwin, C. Yi, B.D. Cook, W. Wang, A.S. Denning, R. Teclaw, and J.G. Isebrands, Quantification of regional and continental scale surface fluxes of carbon using the WLEF tall tower (invited). 29 May, 2001. Spring AGU meeting, Boston, MT.

Davis, K.J., C. Yi, B.W. Berger, R. Kubesh and P.S. Bakwin.Tall tower observations of scalar budgets in the continental boundary layer (invited). 7 October, 2000. Workshop on co2 boundary layer budget methods, 5-8 October, 2000, Gubbio, Italy

Davis, K.J., B.W. Berger, B.D. Cook, C. Yi, W.Wang, P.S. Bakwin, C. Zhao, J. Isebrands and R. Teclaw Closing the carbon dioxide budget of North America: Observations and methods from northern Wisconsin. Invited colloquium, 25 September, 2000, Department of Atmospheric and Oceanic Sciences, University of Wisconsin.

Zhang N., S.A. Denning, C. Yi, K.J. Davis, P.S. Bakwin, and M. Branson, Covariance of the ecosystem carbon dioxide flux and the PBL depth at the tall tower in northern Wisconsin: Observations and simulations, NOAA, Climate Monitoring & Diagnostics Laboratory Annual Meeting, May 3-4, Boulder, Colorado, 2000.

Davis, K.J., B.W. Berger, B.D. Cook, R. Kubesh, W. Wang, C.Yi, P.S. Bakwin, C. Zhao, J. Isebrands and R. Teclaw, 2000. Forging a link between AmeriFlux and Globalview-CO2. Presentation at the annual meeting of NOAA CMDL. 3-4 May, 2000.

Davis, K.J., P.S. Bakwin, B.W. Berger, B.D. Cook, and C. Yi. 1999. Flux budgets and CO_2 profiles in the atmospheric boundary layer. Fall AGU meeting, San Francisco, CA.

Denning, A.S., N. Zhang, K.J. Davis, C. Yi, P.S. Bakwin and B.W. Berger, 1999. Simulations and observations of diurnal coupling between ecophysiology and the atmospheric boundary layer as a control on CO_2. Fall AGU meeting, San Francisco, CA.

Denning, A.S., P.-L. Vidale, L. Prihodki, N.P. Hanan, K.J. Davis, and P.S. Bakwin. Simulations and observations of forest-atmosphere interactions across spatial scales at the WLEF-TV tower in Wisconsin. Paper presented at Amer. Geophys. Union Fall Meeting, San Francisco, Calif., 1998.